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DEVELOPMENT OF A MULTICUSP H⁻ ION SOURCE
FOR ACCELERATOR APPLICATIONS

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ABSTRACT

The development of a multicusp surface-production H⁻ ion source (Berkeley concept) designed specifically for accelerator use is described. The goal of this development effort has been to provide a suitable H⁻ ion source for the Proton Storage Ring now being constructed at LAMPF. The ion source that has been developed is now capable of long-term operation at 20 mA of H⁻ current at 10% duty factor and with normalized beam emittance of 0.13 cm-mrad (95% beam fraction). The development program will be described with particular emphasis on beam emittance measurements.

INTRODUCTION

A multicusp surface-production negative ion source has been developed at LAMPF to satisfy the operation of the Proton Storage Ring as well as existing LAMPF requirements. This source must provide an H⁻ beam with a peak intensity of 20 mA and sufficient quality to match the acceptance of the accelerator. To insure an accelerator quality H⁻ ion beam the geometrical admittance of the extracted beam was collimated in the ion source and thus the geometrical admittance of the ion source was used to determine the emittance of the extracted beam. In fact, it has been found that the measured emittance values are somewhat higher than the geometrical admittance predictions.[1] With this restriction, the operating parameters of the ion source were studied in an attempt to increase the beam brightness.

EXPERIMENTAL APPARATUS

The H⁻ ion source development program has been carried out at the high-voltage test stand in the LAMPF injector complex.[2] The test stand provides the capability of intensity and emittance measurements for both unanalyzed and mass-analyzed beams. Beam currents are measured using both beam-current toroids and biased Faraday cups. The beam-current monitors have been calibrated using the LAMPF H⁺ duoplasmatron and the absolute accuracy of the beam current measurements is better than 3%. The emittance scanners are conventional slit and collector systems with spatial resolution of 0.2 mm and angular resolution of .15 mrad. The emittance data are processed by the SEL 840 LAMPF control computer and on-line reanalyzed emittance scans are provided to the test stand.

CUSP FIELD MAGNETS

CONVERTER

FILAMENTS
REPELLER
ELECTRODE

CESIUM CELL
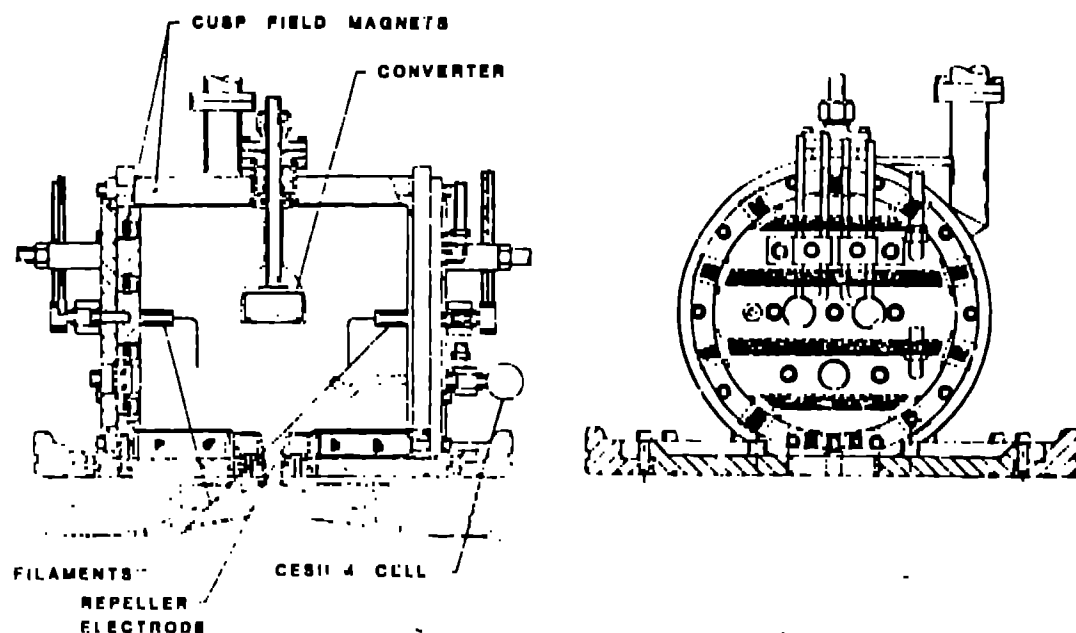
(a)   (b)

Fig. 1.   (a)A top view of the cylindrical source design.
          (b)A side view of the cylindrical source design where the
             shaded areas represent the permanent magnets.

The prototype Ion source used In these experiments Is similar
to the Berkeley source.[3] The source employs a cylindrical geometry
with ten magnets around the cylinder and four magnets In each
endplate as shown In Fig. 1. The cylindrical design Is large
enough to accommodate a 5 cm diameter converter In the magnetic
field-free region In the center of the source. A 0.154 cm tungsten
filament, approximately 18 cm In length, Is mounted In each
endplate. Water cooling Is provided to the converter, the
filaments, the endplates, the repeller electrode, and each of the
ten magnets. The source housing Is only cooled Indirectly through
contact with the Individual magnet holders. As shown In Fig. 1(a),
the geometrical admittance of the source Is defined by the diameter
of the 5 cm converter and particle flight path of 12.9 cm to the
1.27 cm diameter channel In the repeller electrode. The Ion beam Is
extracted through a break In the cusp field geometry. The magnets
are positioned symmetrically around the source housing, extending
the length of the cylinder except along the beam axis. There are
breaks In the bar magnets along the beam axis to allow for
Installation of the converter and for beam extraction. As shown In
Fig. 1(b) magnets are positioned above and below the extraction
aperture In a symmetric manner In the repeller electrode to minimize
plasma loss area and to provide an essentially magnetic field-free

region for beam extraction. All of the magnetics around the cylinder and in the endplates are samarium-cobalt magnets except for the three bar magnets on the extraction side of the source and those in the repeller electrode. It was necessary to make these magnets Alnico-8 magnets to insure a magnetic-field-free extraction region.

EXPERIMENTAL RESULTS

Cesium Transfer

Originally cesium was transferred into the source using a method similar to that used by the Berkeley group. First, the source was conditioned by running relatively high continuous arc currents (40 to 50 amps) for several hours. The ratio of H^- current to heavy ion impurity current was monitored to measure the condition of the source. When the ratio of H^- ion current to impurity current (primarily O^- and OH^-) was unity, cesium was transferred by heating the cesium oven to 270° C and opening the valve of the oven for approximately one minute. With this method of transfer, the source was found to operate stably for up to 24 hours. However, the period of stable operation varied from one transfer to another.

To achieve greater long term operational stability, a method of continuous cesium transfer was adopted. A temperature controller was used to regulate the temperature of the cesium oven. Thus, after the source was conditioned the cesium valve was left open and the flow of cesium into the source was determined by the temperature of the oven.

This method of cesium transfer gives us the capability of studying the various source parameters under controlled cesium conditions. For an arc current of 40 A, a pulse length of 800 μsec,
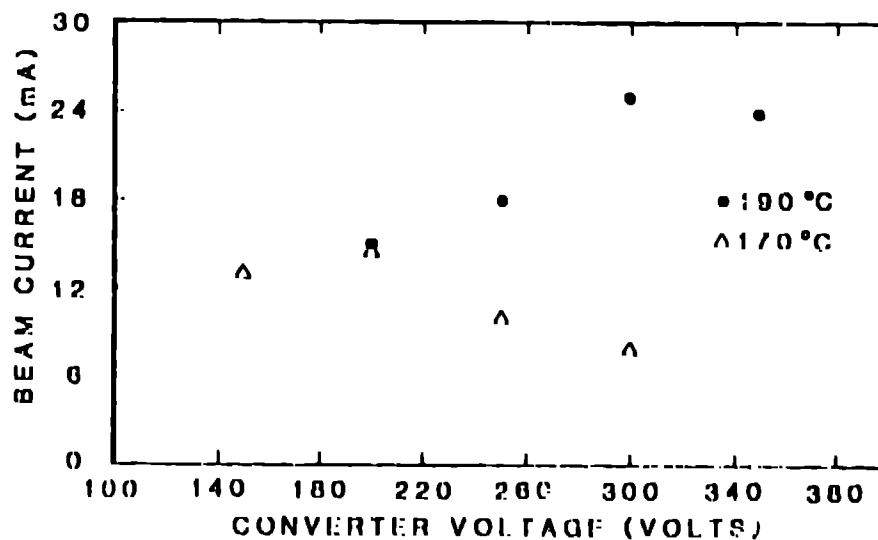

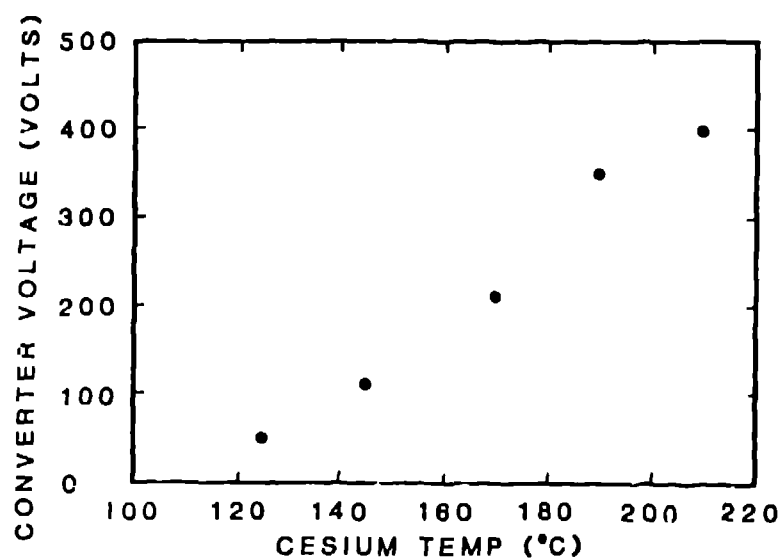Fig. 2. Beam current vs converter voltage for two different cesium oven temperatures.

CONVERTER VOLTAGE (VOLTS)

500

400

300

200

100

0

100   120   140   160   180   200   220

CESIUM TEMP (°C)

Fig. 3. Converter voltage for maximum beam current
vs cesium-oven temperature.

BEAM CURRENT (mA)

30

24

18

12

6

0

100   120   140   160   180   200   220
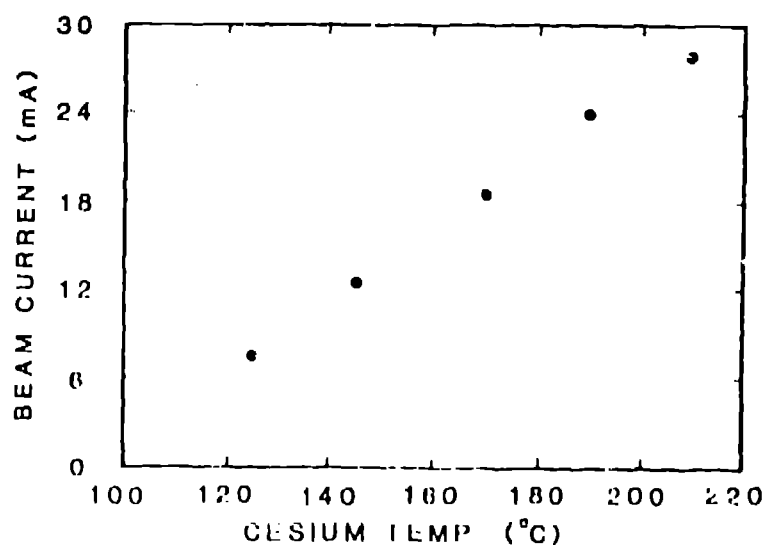
CESIUM TEMP (°C)

Fig. 4. Maximum beam current as a function of cesium oven
temperature.

a repetition rate of 120 Hz, and a molybdenum converter, a study of converter voltage and cesium temperature was performed. At each cesium-oven temperature, we found a converter potential which yielded the maximum beam current. Two typical converter voltage versus beam-current scans are shown in Fig. 2. In general, the greater the cesium transfer rate, the higher the optimum converter voltage and the larger the maximum beam current. Fig. 3 shows the

plasma potential. The small amount of data that was obtained indicated this converter did not yield significantly more beam current even though it drew approximately twice as much converter current as the molybdenum.

A niobium converter was also installed in the same geometry as the molybdenum converter. Its operation was very similar to the molybdenum in terms of sparking and converter current. However, the niobium yielded both a brighter and higher-intensity beam than the molybdenum when operated under the same conditions as shown in Fig. 6. At an intensity of 20 mA, the niobium converter produced a beam that is 1.5 times as bright as that of molybdenum. Although the beam quality is improved, a niobium converter may have some long-term operational problems. When the source was disassembled, the surface of the converter was badly spalled and cracked.

Lifetime Tests

Several lifetime tests were carried out to evaluate the long-term performance of this ion source for accelerator service. The source was operated for extended periods up to 200 hours and ion beam measurements were taken continuously during the tests at periodic intervals. The tests were terminated either by accelerator failure or by choice but not because of ion source failure. In general, the beam-current and emittance values were constant to
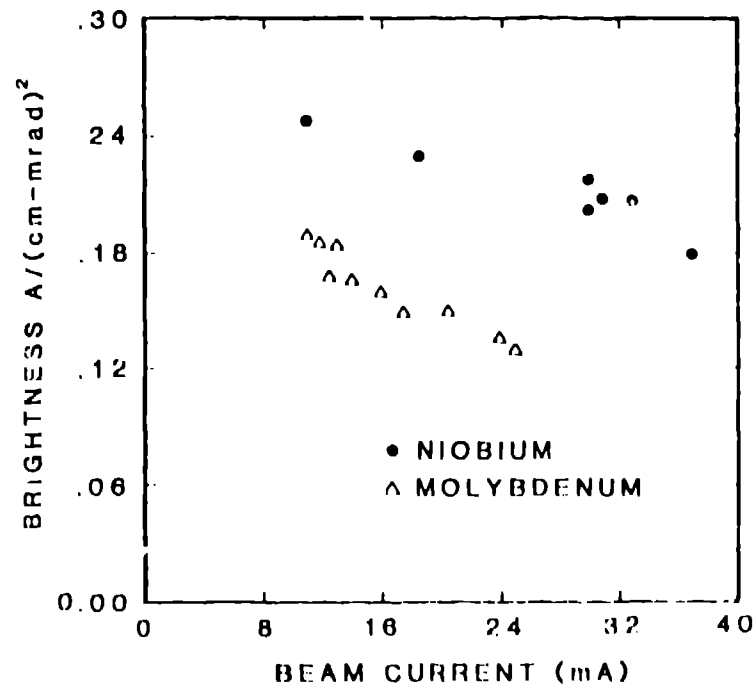

Fig. 6. Beam brightness vs beam current for identical converters made of niobium and molybdenum.

variation of the optimum converter voltage as a function of cesium-oven temperature. In Fig. 4, the beam currents corresponding to the converter voltages shown in Fig. 3, are plotted as a function of the cesium-oven temperature.

Thus, Fig. 4 indicates that higher beam currents can be obtained by simply transferring cesium at a higher rate. However, since the measured emittance values are determined by the geometrical admittance of the source, these higher beam currents at higher converter voltages have higher emittance values. All of the emittance values measured at the various cesium temperatures are plotted in Fig. 5 as a function of beam current. This plot shows that over the range of cesium conditions investigated, the observed emittance values increased with beam current.

To further investigate now the beam current yield depends on cesium-transfer rate the source was operated at various duty factors. When operated at low duty factor (1%), the source performance was equivalent to that at higher duty factor (8%), but the source required a lower rate of cesium transfer. The measured emittance values at lower duty factors exhibit the same relationship to beam current shown in Fig. 5.

Converter Material Study

In the development program, a molybdenum converter has been used in most of the testing. However, titanium and niobium converters have also been tested. The titanium converter was extremely difficult to operate. The converter surface sputtered severely and this sputtering caused sparking that made it very difficult to maintain the voltage on the converter. There was also evidence of the titanium converter pumping a significant amount of hydrogen, especially when the converter was allowed to float at
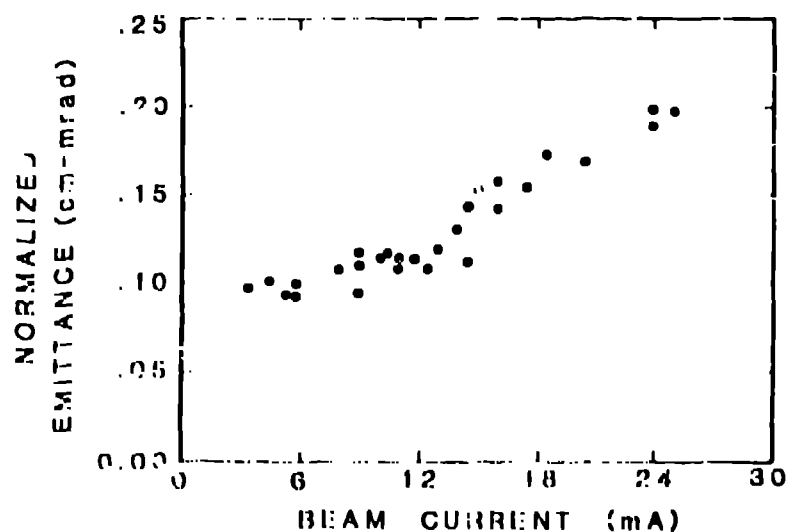

Fig. 5. Normalized emittance vs beam current.

within ±5% of setpoint values after equilibrium had been reached. During these tests, neither the arc nor the gas flow had closed-loop control, so the above variations reflect the open-loop behavior of the source. A hydrogen-gas controller has now been installed and the present performance is deemed adquate for LAMPF operation.

At the end of each test, the tungsten filaments were removed and measured. On the average, the diameter of the filaments decreased 0.001 inches/100 hours of operation for 20 mA beam operation. This sputtering rate implies a 600 hour filament lifetime (10% reduction in diameter). However, some regions of the filaments near the cesium transfer tube did exhibit a greater reduction in diameter which would entail a shorter lifetime. This transfer tube has been moved farther from the filaments and a more uniform reduction in filament diameter is now expected. The cesium consumption for 20mA operation was 0.012 grams/hour. Thus, the present design is expected to have an operating lifetime in excess of 500 hours; with suitable improvements, a 1000 hour lifetime can be achieved.

CONCLUSION

The multicusp surface-production negative ion source can provide moderate intensity beams at high duty factor suitable for long-term accelerator operation. Peak beam currents of 38 mA have been obtained with normalized emittances less than 0.20 cm-mrad and ion source lifetimes in excess of 500 hours can be expected. Although development work is continuing to obtain brighter beams at the 20 mA level, the present performance of this source is deemed adquate for operation of the Proton Storage Ring at LAMPF. Installation of the source into the 750 kV Cockeroft-Walton dome has begun.

REFERENCES

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